CONCAVE RELIEF SURFACE ROUGHNESS

FLOW RATE SENSITIVITY ANALYSIS

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This report evaluates the effect of concave relief surface roughness on the fluid flow rate of an internal flow path. Flow rate and pressure differential measurements were collected with a Superflow SF-1020 flow bench for a range of implementations of the surface treatment; the parameters varied include the relief radius, spacing, and depth. It was found that the effects of the surface treatments varied significantly; the difference in flow rate relative to that of no surface treatment is inversely related to the pressure differential.

HYPOTHESIS

The implementation of surface roughness, in the form of concave reliefs applied to the wetted surface of an internal flow path, can be observed within the aftermarket automotive performance industry. It is often claimed that this surface treatment increases the fluid flow rate for a given flow path and pressure differential by decreasing the boundary layer thickness. This report evaluates the effects of this surface treatment on the fluid flow rate of an internal flow path.

INSTRUMENTATION

The SuperFlow SF-1020 flow bench was utilized to collect flow rate and pressure differential measurements. It can achieve a maximum flow rate of 0.472 [$m^3 s^{-1}$] ± 10 [%] at 6178 [Pa]. It has a full-scale flow rate accuracy of ± 1 [%] and a pressure differential accuracy of ± 12.75 [Pa]. Measurements are repeatable within ± 0.5 [%] of the relevant full-scale value. [1]

IMPLEMENTATION

The surface treatment was evaluated for an internal flow path with a 60 [mm] diameter and 90 [mm] length. The concave reliefs applied are staggered patterns defined by a constant radius, center-to-center distance, and maximum depth. A comprehensive list of the configurations evaluated is presented in Table 1.

PATH ID [-]	A [mm]	B [mm]	C [mm]
-.--A:-.--B:-.--C	-	-	-
0.75A:1.50B:0.25C	0.75	1.50	0.25
0.75A:1.50B:0.50C	"	"	0.50
0.75A:1.50B:0.75C	"	"	0.75
0.75A:2.25B:0.25C	"	2.25	0.25
0.75A:2.25B:0.50C	"	"	0.50
0.75A:2.25B:0.75C	"	"	0.75
1.50A:3.00B:0.50C	1.50	3.00	0.50
1.50A:3.00B:1.00C	"	"	1.00
1.50A:3.00B:1.50C	"	"	1.50
1.50A:4.50B:0.50C	"	4.50	0.50
1.50A:4.50B:1.00C	"	"	1.00
1.50A:4.50B:1.50C	"	"	1.50

where,

A [mm]: constant radius

B [mm]: center-to-center distance

C [mm]: maximum depth

Table 1: Flow Path Configurations

The flow paths are physically retained by an adapter for the SF-1020 flow bench. A 12 and 9 [mm] radius were applied to the adapter flow path interface inlet and flow path outlet edges respectively, to minimize the effects of external flow conditions. The flow paths and adapter were 3D printed with UV sensitive resin and polylactic acid respectively. The generic implementation of a flow path and adapter is presented in Figure 1.

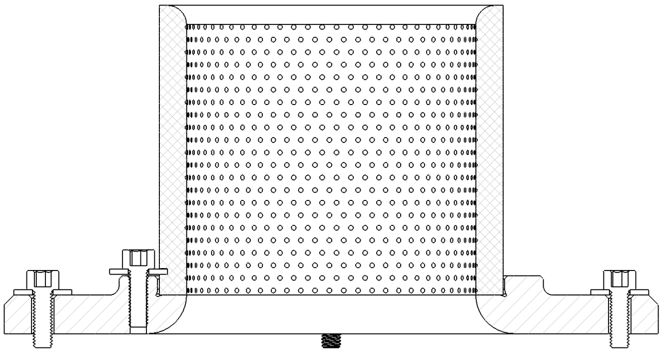


Figure 1: Generic Implementation

METHODOLOGY

The SF-1020 flow bench was configured for exhaust flow, for a pressure differential between the internal and external (environment) pressure references. The flow range utilized for each measurement was selected so that the resulting flow rate measurement was within 70 to 100 [%] of the nominal full-scale flow rate, according to the SuperFlow SF-1020 Operator Manual; the 70 [%] and nominal full-scale flow rate for each range are presented in Table 2 [1].

RANGE ID [-]	70 [%] FLOW RATE [m^3s^1]	FULL-SCALE FLOW RATE [m^3s^1]
1	0.008	0.012
2	0.017	0.024
3	0.047	0.047
4	0.033	0.071
5	0.067	0.094
6	0.099	0.142
7	0.132	0.189
8	0.165	0.236
9	0.231	0.330
10	0.330	0.472

Table 2: SF-1020 Flow Rate Ranges

Flow rate and pressure differential measurements were collected for pressure differential targets in 1000 [Pa] increments in the range of 1000 to 9000 [Pa]. Pressure differential targets were set in an increasing order to minimize error due to instrumentation hysteresis. Measurements were collected approximately 15 [s] after the flow rate stabilized; this was done to minimize error due to windowed filtering of the pressure differential.

ANALYSIS

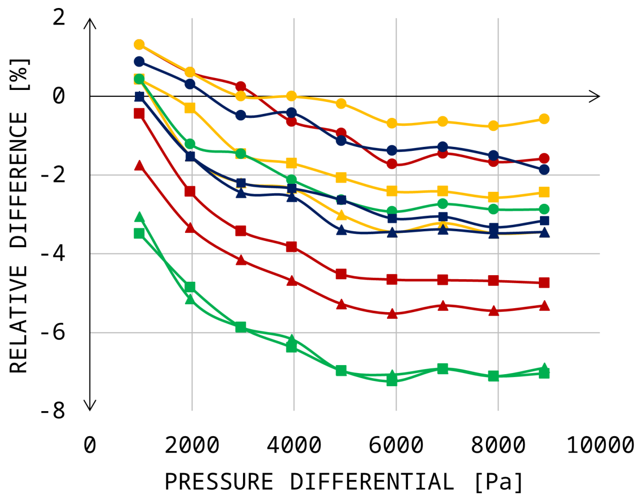
The implementation of surface roughness, in the form of concave reliefs applied to the wetted surface of an internal flow path, resulted in a decrease of flow rate for a pressure differential greater than 4000 [Pa]. An increase of flow rate was observed for six of the evaluated surface treatments, for a pressure differential lower than 4000 [Pa]. The difference in flow rate relative to that of no surface treatment is calculated according to Equation 1.

$$E_r = \frac{\dot{V}_m - \dot{V}_r}{\dot{V}_r} \cdot 100 \quad (1)$$

where,

E_r	[%]:	relative difference
$\dot{V}_r$	[m^3s^1]:	untreated surface flow rate
$\dot{V}_m$	[m^3s^1]:	treated surface flow rate

The relative flow rate difference is inversely related to the pressure differential, for all evaluated surface treatments (presented in Figure 2); the minimum and maximum are 1.31 and -7.24 [%].



where,

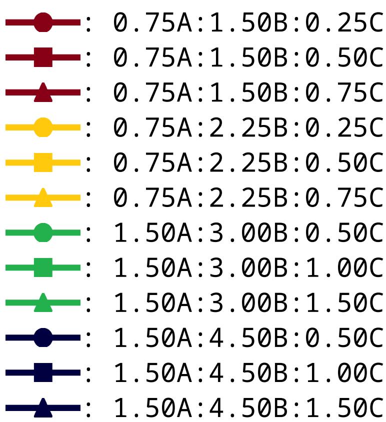


Figure 2: Flow Rate Sensitivity Analysis

REFERENCES

[1] "SF-1020 Flowbench Operator Manual." Apr. 2020.